REVIEW

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A review on the efficacy of *Ocimum gratissimum*, *Mentha spicata*, and *Moringa oleifera* leaf extracts in repelling mosquito

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Abstract: @@@In recent times, repellents and synthetic drugs have been identified as having negative toxicity effects on humans and the environment. Apart from the unfavourable effects on man and livestock caused by these chemicals-based (synthetic) repellents, they are also expensive, non-biodegradable, and no more effective because mosquitoes are getting adapted. With these drawbacks, an eco-friendly plant-based insecticide as a substitute is needed urgently. This paper reviews the extraction and use of essential oil from the leaves of *Mentha spicata*, *Ocimum gratissimum*, and *Moringa oleifera* as mosquito repellent. Carvone, Eugenol, and 9-Octadecenoic acid were discovered to be the most active components in the *M. spicata*, *O. gratissimum*, and *M. oleifera* extracts, respectively, using gas chromatography-mass spectrometry (GC-MS).

Highlights: 1. In recent times, repellents and synthetic drugs have been identified as having negative toxicity effects on humans and the environment. Apart from the unfavorable effects on man and livestock caused by these chemical-based (synthetic) repellents, they are also expensive, non-biodegradable, and no more effective because mosquitoes are getting adapted.

2. An eco-friendly plant-based insecticide as a substitute is needed urgently.

3. Diseases transmitted by mosquitoes are still a significant reason for the global mortality rate, with over 700 million individuals experiencing such diseases every year.

With the proper formulation of other repellent forms using their oils, they can replace non-degradable synthetic mosquito repellents since they are eco-friendly. In general, the mosquitocidal activity and percentage protection of plant extract increase with increasing concentration of the extracts in different formulations.

This paper is our original work. We certify that this manuscript has not been published in part or whole elsewhere in any language, and it has not been submitted to any other journal for reviews.

Keywords: Mosquito, Essential oil, Extraction, Repellent, *Ocimum gratissimum*, *Mentha spicata*, *Moringa oleifera*

1 Background

Mosquitoes cause inconvenience by their bites, as well as the transmission of deadly diseases [1]. Fewer than 10% of the roughly identified mosquito species are viewed as proficient vectors and pathogenic carriers of infections

with significant effects on human health and well-being, both directly and indirectly.

Diseases transmitted by mosquitoes are still a significant reason for the global mortality rate, with over 700 million individuals experiencing such diseases every year [2].

Diseases carried by mosquitoes affect the economy, incorporating loss in business and work yields, especially in nations with marine and temperate atmospheres;

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however, anywhere in the world is prone to vector-borne infections [3]. Various diseases like; Filariasis, Malaria, yellow fever, Japanese encephalitis, zika virus, Dengue fever, etc., are transmitted by mosquitoes [4]. Malaria is among the biggest public health issues globally. Especially in parts of Africa, in which Nigeria has the largest amount of cases of malaria [5].

However, over time, the constant application of synthetic insecticides has culminated in mosquito resistance. This is due to their adaptation and ability to develop resistance to the active ingredient of the chemicals and also changes in its metabolism and behaviour. Mosquitoes have compound forms of identifying their hosts, and various types of mosquitoes react to various stimuli. Some mosquitoes are active in the dawn and dusk, but during the day, there are also mosquitoes searching for hosts [6]. In other to prevent being bitten by mosquitoes, materials, or actions that attract them are advised to be avoided even as their repellents are being applied. And also, the acts that reduce the repellent's effectiveness should be averted [6].

Mosquito repellents generally function by hindering the capacity of the female mosquito to recognize the external stimuli (for example, Carbon-dioxide, water vapor, and heat) that she utilizes to spot a host [7]. Various synthetic and plant-based chemicals are available and are known to ward off mosquitoes. *N,N*-Diethyl-meta-toluamide, also called DEET, is the most frequently used synthetic chemical repellent. Since it became commercially available, it has been implemented above one million times in the 40+ years of its existence. DEET-based insect repellents cause irreparable harm to the environment since they consist of chemicals that are not easily degraded, and their associated neurotoxicity [8]. An alternative to repelling mosquitoes could be plant-based natural materials like plant oils to prevent the adverse effects of synthetic repellents. In comparison with synthetic repellents, they are deemed safe and good for the environment [9].

Before the application of synthetic substances, the repellent features of plants on mosquitoes as well as other pest insects were well known. Humans historically used natural compounds to shield themselves from insect bites [10]. Since ancient times, man has utilized plant parts and secondary plant metabolites for pest control. During the pre-DEET period, vector mosquito reduction relied primarily on the environmental control of the breeding surroundings, i.e., depleting the source. During this time, Pyrethrum, Anabasine, Quassia, Camphor, Turpentine, Nicotine, Derris, D-limonene, Hellebore, Azadirachtin,

Fig. 1 Spearmint leaves [26]

and Chrysanthemum were some plant-based (botanical) insecticides used in different countries [11].

As a possible source of insecticidal materials, the plant kingdom has been of considerable interest. Many plant kingdom species produce a variety of secondary metabolites that perform a crucial role in plant defence against mosquitoes/insects. Plants are a great source of biologically active chemicals/compounds and can be a substitute source for mosquito repellent products [12]. Furthermore, unlike regular insecticides that consist of a sole active ingredient, insecticides derived from plants contain botanical mixtures of chemicals/compounds that work collectively on processes, both physiological and behavioural [13].

Biologically active compounds derived from selected plants species such as *Ocimum gratissimum* (*O. gratissimum*), *Hyptis suaveolens* (*H. suaveolens*), *Azadirachta indica*, and *Eleusine indica* have been commonly used in the past to control insects in many tropical countries [14]. The use of compounds from plants for controlling mosquitoes has been accounted for since 1933, and these chemicals in their essential oils obtained from the various plants have shown to be a feasible alternative to synthetic repellents and also exhibit good repellence against mosquitoes [15]. Extracts and essential oil from plants can be a replacement for synthetic insecticides since they are efficient, easily decomposable, environmentally friendly, and relatively cheap.

Essential oils, which are volatile substances, have an oily scent and are derived from the various parts of the plant [16]. They are extracted with diverse methods, and plant parts used for their isolation include leaves, stem bark, flowers, and roots [17].

Fig. 2 a–d *Moringa oleifera* tree, leaf, pod and seed, respectively. Source: [34]

2 Main text

2.1 Forms of mosquito repellent

1. **Aerosol**—The most commonly used form of repellents for mosquito is aerosol. It comprises of a propellant, a solvent, and other components. The active ingredient is diluted to a particular concentration by ethanol or propyl alcohol, the solvent. It also holds the mixture of all the materials, so that even after extended storage, the product will still be active. They are packed and discharged as a spray under pressure [18].
2. **Cream**—Repellent creams for mosquito make the individual unattractive to the biting mosquitoes. The smell of the skin and human breathe attracts mosquitoes and other insects that feast on blood. Carbon dioxide is released by humans once they breathe out, and this draws insects. The skin is rendered unattractive to mosquitoes by the application of this repellent cream. Thus, the mosquitoes will be seen flying around, but it will not bite you [19].
3. **Stick**—These repellent incense sticks are plant-based and DEET-free. The sticks use a combination of citronella, rosemary, peppermint, lemon grass, cedar wood, and bamboo to ward off mosquitos [20]. They release fragrant smoke when they are burnt, which

Fig. 3 *Ocimum Gratissimum* plant (Scent leaf). Source [43]

also wards off mosquitoes around the place of burning.

4. **Mosquito coil**—A mosquito coil is an incense for repelling mosquito, usually shaped into a spiral. It is generally kept in the middle of the spiral, holding it in the air. Its working mechanism is also identical with the incense stick, and candle as its burning normally starts at the far end of the spiral and moves toward the middle of the spiral, creating smoke that repels mosquitoes [21].

There are many mosquito repelling plants, both wild and cultivated. It is imperative to note that the repelling

Table 1 Comparative analysis of *Ocimum gratissimum*, *Mentha spicata*, *Moringa oleifera*, and other leaf extracts as a repellent for mosquito. Sources: [12, 28, 38, 55–59]

S. no	Extract	Work done	Methodology	Results	Gaps	References
1	<i>M. oleifera</i> leaf extracts	Larvicidal and repellent potential of <i>Moringa oleifera</i> against <i>Anopheles stephensi</i> liston	Soxhlet extraction method was used with methanol as solvent to isolate the oil. The oil extract was dissolved in isopropanol alcohol which served as the test sample applied at different concentrations	At 100% concentration, 90.41% repellence was observed, and 23.28% repellence decreased after 20% concentration was treated	The study was limited due to the use of one plant No analysis for the extract to know the active component and functional groups	[38]
2	<i>Hyptis spicigera</i> , <i>Ocimum basilicum</i> , and <i>Striga hermonthica</i> leaf extracts	Mosquito repellent activity and phytochemical characterization of essential oils from <i>Hyptis spicigera</i> , <i>Ocimum basilicum</i> , and <i>Striga hermonthica</i> leaf extracts	The essential oils were obtained using the Soxhlet extraction method. Arm-in-cage technique 55e was applied for the repellency test with two human volunteers. Phytochemical and FTIR analysis were performed on the extracts	At 50% concentration, <i>O. basilicum</i> and <i>Hyptis spicigera</i> oil exhibited higher repellent potential on <i>Anopheles gambiae</i> with protection time of 183 and 120 min, respectively, while <i>H. spicigera</i> and <i>S. hermonthica</i> had protection time of 180 and 175 min, respectively, against <i>Anopheles gambiae</i> .	Failure to incorporate the oils into any repellent form as the oils was used in their raw form for the repellence test No GC-MS analysis for active components of the extracts	[55]
3	<i>Lantana camara</i> and <i>Ocimum gratissimum</i> leaf extracts	<i>Lantana camara</i> and <i>Ocimum gratissimum</i> crude extracts and fractions as Mosquito repellents against <i>Aedes aegypti</i>	Maceration method was used for isolating the oils using 3 solvents. Extracts were incorporated into cream formulation for the test sample with 3 volunteers	For hexane fraction extract, at the lowest dose of cream applied, a total protection time of 60 min was achieved with 63% and 64% protection for <i>Ocimum gratissimum</i> and <i>L. camara</i> , respectively	Incorporation of the extracts into one repellent form Failure of analysis of extracts for active ingredients or functional groups	[56]
4	<i>Moringa oleifera</i> and <i>Stachytarpheta Indica</i> leaf extracts	Repellent activities of <i>Moringa oleifera</i> and <i>Stachytarpheta Indica</i> leaf extracts against aedes aegypti mosquito	Soxhlet extraction was used for the extraction of the oils with rotary evaporator afterwards. The net cage testing method was applied with human volunteers using different test concentrations. Average amount of mosquitoes that settled on each arm of the volunteer was noted	At the highest test concentration (40 g/l), <i>Stachytarpheta Indica</i> showed the highest percent repellence (90.47%) while <i>Moringa oleifera</i> showed the lowest percent repellence (4.76%) at the lowest test concentration (20 g/l)	Failure of analysis of the extracts for active component and functional groups	[12]
5	<i>Tagetes minuta</i> and <i>Lippia javanica</i> leaf extracts	Repellency features of plant oils of <i>Tagetes minuta</i> and <i>Lippia javanica</i> as mosquito repellents	Hydro-distillation method was used to extract the oils. Repellence bioassay was done using the human-bait technique with four volunteers	<i>T. minuta</i> and <i>L. javanica</i> showed different levels of repellence against female <i>An. gambiae</i> with 10–195 min and 40–170 min protection time for the lowest and highest concentrations, respectively	The essential oils were incorporated into only one repellent form	[57]
6	<i>Hyptis suaveoleons</i> and <i>Ocimum gratissimum</i> leaf extracts	<i>Hyptis suaveoleons</i> and <i>Ocimum gratissimum</i> against mosquito (<i>Aedes aegypti</i>)	Soxhlet extraction method was used to isolate the oils with methanol solvent. The control solution was prepared by dissolving the oil in ethanol using different concentrations	50% and 33.33% protection was offered by <i>H. suaveoleons</i> and <i>O. gratissimum</i> against the mosquito bite for 6 h at the concentration of 0.03 mg/cm ²	Failure of analysis of the extracts for the active compounds. Use of ethanol for test solution limits the repellent effect of the extracts as the alcohol cannot prolong the effect of essential oils due to its volatility	[58]

Table 1 (continued)

S.no	Extract	Work done	Methodology	Results	Gaps	References
7	<i>Cymbopogon citratus</i> (lemongrass) leaf extract	Analytical investigation of <i>Cymbopogon citratus</i> (lemongrass) leaf extract as mosquito repellent	Soxhlet extraction method was used for isolation of the oil. Oil was incorporated into a cream as test sample	<i>Cymbopogon citratus</i> repelled mosquitoes for about 8 h for the highest test concentration of 2.0 ml, while for the least concentration of 0.5 ml, repelled mosquitoes between 1 and 2 h of application	The study is limited due to the use of one plant The oil was incorporated into only one repellent form	[59]
8	<i>Hyptis suaveolens</i> , <i>Mentha spicata</i> and <i>Cymbopogon citratus</i>	Oil extract from local leaves; an alternative to synthetic mosquito repellents using <i>Hyptis suaveolens</i> , <i>Mentha spicata</i> and <i>Cymbopogon citratus</i>	Soxhlet extraction method was used. The oil extracts were incorporated into a cream formulation which served as the test sample and the open room testing was used with four volunteers	Largest amount of extract incorporated into the cream (0.6 ml) for <i>Hyptis suaveolens</i> provided the highest repellence of up to 8 h, while for both <i>Mentha spicata</i> and <i>Cymbopogon citratus</i> , it repelled mosquitoes between 4 -5 h for same concentration	Extracts were only incorporated into one form of repellent No FTIR analysis for identification of functional groups of extracts	[28]

Table 2 FT-IR spectrum of *Ocimum gratissimum* leaf extract. Source: [60]

Peak values	Functional groups	Bonding pattern
3395.79	Amines, imines associated	N–H str
2947.54	Alkanes (–CH ₃)	C–H str
2837.65	Alkanes (–CH ₃)	C–H str
2527.88	Phosphorus/organo sulphur compounds	O–H/S–H str
2049.46	Deuterated alkanes	C–D str
1571.67	Alpha–Halogenonitro compound	NO ₂ str
1404.07	Phenols, Tert, alcohols	O–H def
1262.51	Nitrates	O–NO ₂ v
1118.69	Secondary alcohols	C–OH str
1024.5	Primary alcohols	C–OH str
756.11	Benzene ring with three hydrogen H atoms	C–H def
695.60	Haloids	C–Cl str
652.97	Disubstituted alkenes (R1 CH = CHR2) Cis	C–H def

is carried out by compounds situated inside the plants. Common plants that repel mosquitoes include; Citronella plant, lemon grass, lavender, mint, catnip, rosemary, garlic, basil, floss flower, beebalm, etc.

2.2 *Mentha spicata*

Mentha spicata, also known as spearmint, is a genus from the *Lamiaceae* (mint) family, and plants belonging to this family are a great source of polyphenols with good antioxidant features [22]. Spearmint essential oils have often been utilized in different ways, like plant diseases and insect pest control, in conventional medicine, and also in cosmetics and culinary [23]. Spearmint is native to northern England and is cultured in tropical to moderate climate zones like Europe, South Africa, America, China, and Brazil. These days, it is grown extensively all around the world [22]. Because of its invasive, creeping rhizomes, gardeners usually plant it in containers or planters, and its leaves can still be used clean, frozen, or dry [24].

The most copious chemical in spearmint oil is R-carvone, giving its distinctive scent to spearmint [25, 26]. Spearmint essential oil was successful as a mosquito larvicide. Because of its toxicity and negative environmental effect, the application of spearmint as a larvicide would be a better substitute for conventional insecticides [25]. Carvone is noted to have the potential of preventing the growth of bacteria, and also acting as an insect repellent and fungicide [22]. Spearmint leaves were chosen because its essential oil is a good natural insect repellent

Table 3 FT-IR spectrum of *Moringa oleifera* leaf extract. Source: [61]

Major peaks (cm ^{−1})	Functional groups	Bonding pattern
3000–3500	Phenols	OH stretch
3200–3500	Alcohols	O–H stretch
3100–3500	Amines	N–H stretch
2800–3000	Alkanes	C–H stretch
2500–2750	Carbonyl	H=CO stretch
1625–1750	Ketones/esters	C=O bonds
1375–1500	Alcohol Nitro	O–H band N–O symmetric stretch
1244.40	Carbonyl	C–O stretch
1125–1250	Aromatics	Aromatic ring (Ar–O)
675.09–900	Aromatics	Aromatic rings

Table 4 FT-IR spectrum of *Mentha spicata* leaf extract. Source: [62]

Wave numbers (cm ^{−1})	Functional groups	Bonding pattern
3349.81	Alcohol	OH stretch
2927.23	Alkanes (–CH ₃)	C–H stretch
1633.44	Alkene	C=C
1537.09	Alkene	C=C stretching
1384.66	Alkane	C–H bending
1253.97	Carbonyl	C–O stretch
1054.89	Carbonyl	C–O stretch
599.76	Aromatics	Aromatic ring

from past work, and its distinctive smell will improve the quality of the repellent forms (Fig. 1).

2.3 *Moringa oleifera*

One of the most commonly grown species of a monogeneric family—the *Moringaceae* is *Moringa oleifera* (*M. oleifera*), and it's indigenous to India's sub-Himalayan regions [27, 28]. *Moringa* is cultivated predominantly in semi-arid, tropical, and temperate regions. In dry sandy soil, it thrives best, tolerating poor soil, and also in coastal regions. It develops in nearly all types of well-drained soils and is resistant to drought and retains water throughout the dry season by shedding of leaves. It is usually grown and naturalized in Mexico, Central and South America, Sri Lanka, tropical Africa, Philippines, India, and Malaysia. [29].

The *Moringa* tree is deemed among the world's most valuable trees; nearly every portion can be used for

Table 5 Chemical composition of essential oil from *Ocimum gratissimum*. Source: [63]

S. no	Compound	RI ^a	% composition	Mass spectra data
1	α-Thujene	926	0.3	136,121,105,91
2	α-Pinene	933	0.3	136,121,93,79,67
3	Sabinene	969	0.7	136,121,107,93,77
4	β-Pinene	976	1.6	136,121,107,93,77
5	Myrcene	990	0.3	136,121,115,107,93
6	Limonene	1027	0.4	136,121,107,93,78
7	Benzyl alcohol	1028	0.7	108,91,79,73,65
8	1,8-Cineole	1029	0.7	154,139,125,108,81
9	Cis-ocimene	1035	8.2	136,121,105,93,78
10	Trans-ocimene	1050	0.9	136,121,101,93,79,53
11	γ-Terpinene	1057	0.6	136,121,105,93,77
12	Artemisia ketone	1062	0.3	136,121,91,83,69,55
13	Linalool	1098	0.3	139,121,97,67,43
14	Pinen-2-ol	1136	Tr	134, 111, 93, 79,55
15	Camphor	1140	1.5	135,119,109,95,69
16	Allo-ocimene	1142	0.3	136,121,105,91,67
17	Borneol	1163	0.6	121,110,95,81,67
18	Terpinene-4-ol	1176	0.3	154,136,125,111,43
19	α-Terpineol	1188	0.3	136,121,107,93,81
20	Citronellol	1226	Tr	138,109,69,55,41
21	Neral	1238	0.8	135,119,109,95,69
22	Linayl acetate	1255	0.5	136,121,105,93,55
23	Geranial	1268	0.5	109,99,95,83,69,53
24	Borneol acetate	1284	0.9	136,121,108,95,67
25	Thymol	1290	Tr	150,135,91,77,65
26	β-Elementene	1300	0.2	208,193,177,165,150
27	Eugenol	1354	61.9	164,149,137,131,121
28	Neryl acetate	1363	0.3	136,121,107,93,53
29	A-farnesene	1453	1.6	133,119,107,93,55,41
30	Ethylcinnamate	1460	0.5	147,133,119,105,91,7
31	Germacrene D	1480	4.4	204,161,147,133,105,91
32	Bicyclogermacrene	1494	0.5	121,107,93,79,67
33	β-Bisabolene	1508	0.8	119,105,93,69,53
34	γ-Cadinene	1513	1.1	161,119,105,91,79
35	Acetyl eugenol	1523	0.3	207,164,149,131,121
36	Elemecin	1553	0.2	208,193,177,165,150
37	Germacrene D-4-ol	1574	0.7	222,207,161,123,95,81
38	Spathulenol	1575	0.9	205,177,119,105,79,55
39	Caryophyllene oxide	1580	0.9	187,107,91,79,55

Table 5 (continued)

S. no	Compound	RI ^a	% composition	Mass spectra data
40	Goussonol	1637	0.4	157,143,135,119,105
41	B-eudesmol	1647	0.2	93,79,67,59,41
42	Tetradecanoic acid	1720	0.8	220,171,115,60,57
43	Bisabolol oxide A	1744	0.1	238,220,202,154,134
44	Benzyl-benzoate	1759	0.5	152,105,91,77,65,51
Total			97.3	

^a Means of identification of samples

nutrition or contains some beneficial property. It is a conventional food crop that has the potentials of improving nutrition, boosting food protection, fostering rural growth, and promote sustainable land management [30]. Every part of *Moringa* has been effectively used against various ailments. Extracts from its leaf exhibit antioxidant and hypo-cholesterolaemic activities [31, 32].

The phytochemicals present in *M. Oleifera* can function as larvicides, repellents, arthropod growth controllers, and also possess a very deterrent behaviour as noticed by many researchers and analysts. Seed extract from *M. Oleifera* has a good effect on malaria and has no adverse impact on humans [33]. *Moringa* plant extracts possess repellent properties and have an extensive range of medicinal applications. Different portions of this plant, like the leaves, fruit, seed, flowers, bark, and roots, contain a list of important purposes [33] (Fig. 2).

2.4 *Ocimum gratissimum*

Ocimum gratissimum, also called basil clove, African basil, is an *Ocimum* species from Africa, South Asia, and South America [35]. It is a species of tropical plants popularly referred to as “scent leaf,” as Nigerians love to call it. In native Nigeria, it is called Nchanwu leaf in (Igbo), Daidoya in (Hausa), and Efirin in (Yoruba). It is a tropical plant species belonging to the Labiatae family [36]. The leaf consists of a variety of nutrients and minerals that provide the plant with many health benefits [37]. It is stated that fresh basil leaves contain protein, magnesium, Anatol, Boron compounds, Eugenol, Tryptophan, Stigmasterol, zinc, Tannin, and Cinnamic acid [38].

They are often used to make soups as a local spice and flavor. *O. gratissimum*'s essential oil primarily contains eugenol, which provides some signs of antibacterial activity as well as a strong mosquito repellent due to its smell

Table 6 Chemical composition of leaf essential oil from *Moringa oleifera*. Source: [64]

Peak	Compound	Molecular formula	Molecular weight	Retention time	Percentage content (%)	Mass peaks
1	4-Hydroxy-4-methyl-2-pentane	C ₆ H ₁₂ O ₂	116	3.29	7.01	42
2	3-Ethyl-2,4-dimethyl-pentane	C ₆ H ₁₂ O	100	4.008	6.14	49
3	3-4-Epoxy-ethanone	C ₉ H ₂ O	128	4.233	1.78	35
4	N-(1-methylethylidene)-benzene ethanamine	C ₁₁ H ₁₅ N	161	9.635	1.54	50
5	3,5-Bis(1,1-dimethylethyl)-phenol	C ₁₄ H ₂₂ O	206	14.250	2.55	94
6	1-Hexadecanol	C ₁₆ H ₃₄ O	242	17.850	1.23	64
7	3,7,11,15-Tetramethyl-2 hexadecene-1-ol	C ₁₆ H ₃₂ O	240	18.425	1.17	67
8	Hexadecanoic acid	C ₁₇ H ₃₄ O ₂	270	19.458	2.03	90
9	L-(+)-Ascorbic acid 2,6dihexadecanoate	C ₃₈ H ₆₈ O ₈	652	20.183	19.66	136
10	Phytol	C ₂₀ H ₄₀ O	296	22.142	4.24	83
11	9-Octadecenoic acid	C ₁₈ H ₃₄ O ₂	282	23.000	20.89	129
12	4,8,12,16-Tetramethyl heptadecan-4-olide	C ₂₁ H ₄₀ O ₂	324	26.133	2.77	172
13	9-Octadecenoic acid-1,2,3-propanetriyl ester	C ₅₇ H ₁₀₄ O ₆	884	26.983	1.23	123
14	14-Methyl-8-hexadecenal	C ₁₇ H ₃₂ O	252	27.533	8.11	222
15	1,2-Benzene dicarb oxylic acid	C ₂₄ H ₃₈ O ₄	390	28.358	2.46	144
16	Octadecamethyl-cyclononasiloxane	C ₁₈ H ₅₄ O ₉ Si ₉	666	9.017	1.23	199

and insect toxicity [39, 40]. Thus, Scent leaf can be mixed into mosquito coils, incense, creams, or ointments to ward off reptiles and insects [41].

It is an herbaceous plant that grows with an upright stem reaching six feet high [42]. Scent leaf, which is a potential repellent plant, was considered for the study as it is cheap, easily accessible (as can be found in the backyard of most homes or local markets) (Fig. 3).

2.5 Essential oil and extraction

The essential oil is a potent water repellent liquid that houses labile plant-based chemical compounds (easily evaporated at normal temperatures) [44, 45]. Often known as volatile oils, they are also named according to the plant they were derived from, like clove oil, which is an essential oil obtained from the clove [46]. The metabolites such as the monoterpenes like camphor, eugenol, citronellol, terpinolene, α -pinene, citronellal, thymol, limonene, and cineole are the usual components in several essential oils showing mosquito repellent behaviour [46].

Extraction "means transferring compounds from a liquid or solid to another solvent or phase [47]. Two immiscible phases are combined to separate a solvent from one phase to the next, depending on the relative solubility in each phase. Extraction is a primary method used in plant materials for separating their compounds. Since essential oils are the liquefied form of the plant, instead of being produced in laboratories synthetically, they are obtained from materials of a plant by extraction methods appropriate for the specific plant component containing

the oils. The common extraction methods for essential oil include; Soxhlet extraction, steam distillation, CO₂ extraction, water distillation, maceration, cold press extraction, and effleurage [48, 49].

2.6 Characterization of the essential oils

Characterization involves the description of the distinctive nature or features of the extracted oils. Characterization is based on different analyses for the extract, such as phytochemicals, gas chromatography-mass spectrometry [GC-MS], and Fourier Transform Infrared Spectroscopy [FTIR] analysis.

2.7 GC-MS analysis

One of the presumed hyphenated analytical techniques is gas chromatography-mass spectrometry (GC-MS). GC-MS is an analytical tool incorporating the features of gas chromatography and mass spectrometry to determine various components in a test sample [50]. Gas chromatography isolates the components of a mixture, and each component is individually identified by mass spectrometry.

GC-MS is used to analyse organic compound mixtures that are unknown, and its application in determining the composition of bio-oils extracted from raw biomass is a key use of this technology [51].

2.8 FTIR analysis

Fourier-transform infrared spectroscopy (FTIR) is used to acquire from a solid, liquid, or gas sample its infrared absorption or emission spectrum. At the same time,

Table 7 Chemical composition of *Mentha spicata* L. essential oil. Source: [65]

Components	RI ^a	% composition	Identification method ^b
Monoterpene hydrocarbons		21.1	
α-Pinene	938	1.2	RT GC MS
Camphene	954	0.2	RT* MS
Sabinene	974	0.6	RT* MS
β-Pinene	978	2.4	RT GC MS
Limonene	1035	16.2	RT* MS
E-β-Ocimene	1050	0.2	RT* MS
γ-Terpinene	1063	0.1	RT GC MS
Terpinolene	1080	0.2	RT GC MS
Oxygenated monoterpenes		71.2	
1,8-Cineole	1036	7	RT GC MS
Z-sabinene hydrate	1067	0.1	RT GC MS
E-sabinene hydrate	1098	0.1	RT GC MS
Terpinen-4-ol	1178	3	RT GC MS
α-Terpineol	1188	2.3	RT GC MS
Dihydrocarveol	1194	0.6	RT GC MS
E-carveol	1217	0.9	RT GC MS
Carvone	1243	56.4	RT GC MS
Bornyl acetate	1288	0.2	RT GC MS
Z-jasmone	1395	0.3	RT GC MS
Sesquiterpene hydrocarbons		5.2	
β-Burbonene	1383	1.2	RT GC MS
β-Cubebene	1390	0.1	RT GC MS
β-Elementene	1391	0.6	RT GC MS
α-Gurjunene	1410	0.2	RT GC MS
E-Caryophyllene	1419	1.5	RT GC MS
α-Humulene	1452	0.1	RT GC MS
γ-Gurjunene	1477	tr	RT GC MS
Germacrene D	1490	1.1	RT* MS
Bicyclgermacrene	1501	0.2	RT* MS
γ-Cardinene	1514	0.2	RT GC MS
δ-Cardinene	1523	0.1	RT GC MS
Oxygenated sesquiterpenes		0.7	
Spathulenol	1578	0.3	RT GC MS
Caryophyllene oxide	1582	0.2	RT* MS
α-Cadinol	1654	0.1	RT GC MS
Aliphatic compounds		0.7	
3-Octanol	991	0.7	RT GC MS
Total identified		98.9	

The bold signifies the major component identified by GC-MS, others are the identified sub-components at different retention times which summed up to the total discovered in bold

^{a,b} Means of identification of samples

an FTIR spectrometer obtains data with high spectral resolution over a broad spectral range [52]. According to [53], “FTIR screening is essentially an experimental analysis technique used to distinguish organic and some

inorganic substances by applying infrared radiation (IR).” The FTIR instrument delivers about 10,000 to 100 cm⁻¹ infrared radiation over a sample, absorbing some radiation and passing through some. Vibrational energy is produced by the conversion of absorbed radiation [54].

Table 1 shows the comparative analysis of the three (3) plant leaf extracts (*O. gratissimum*, *M. spicata* and *M. oleifera*) with other leaf extracts as a repellent for mosquito while the functional groups showing various functional groups found in the oils were reported in Tables 2, 3, and 4, respectively. The FTIR spectrum confirmed the presence of alcohols, phenols, alkanes, alkenes, carbonyl, carboxylic acids, and aromatic compounds in *M. spicata* extract. Alcohols, amines, alkanes, ketones, carbonyl, nitro, and aromatics were the major functional groups present in the *M. oleifera* leaf extract. While the FTIR spectrum of *O. gratissimum* leaf extract revealed the presence of the following functional groups; Amines, Alkanes (-CH₃), Phosphorus/Organo sulphur compounds, Alpha-Halogenonitro Compound, Alcohols, Nitrates, Benzene ring, and Haloids.

From the GC-MS analysis (chemical composition) of the essential oils of the three leaves, 44 compounds were found in *O. gratissimum*, 16 compounds in *M. oleifera*, and 33 compounds in *M. spicata*, as shown in Tables 5, 6 and 7, respectively. The active compound/components of the three extracts are Eugenol (61.9%), 9-Octadecenoic acid (20.89%), and Carvone (56.4%) for *O. gratissimum*, *M. oleifera*, and *M. spicata*, respectively. The result from Table 7 which shows Carvone having the highest composition and most prevalent in *M. spicata* oil corroborates with the result of [66] in which carvone was discovered as the most sufficient compound/component in the extract. The extracts also showed the presence of various biologically active phytochemicals in the GC-MS analysis. The presence of these photochemicals also contributes to the observed medicinal property in addition to the antimicrobial activity of the plant. Among the three leaves, *O. gratissimum* extract is the best repellent plant, followed by *M. spicata* and *M. oleifera*. This is due to the high composition of eugenol (which is a phenol) in the extract as it has been reported not only to control insects like mosquitoes but also to provide a knock-out effect on them [67]. The active component of clove oil, eugenol, is a fast-acting contact insecticide that is effective on a wide variety of insects/pests such as mosquitoes, ants, cockroaches, etc. [68]. Eugenol has little or no residual activity other than a lingering scent of cloves as mosquitoes detest the smell of cloves [69]. 9-Octadecenoic acid, which is the most prevalent compound in *Moringa leaf* oil extract, exhibited moderate repellent activity at 30 min after treatment, according to [70]. According to [12], leaf extracts of *M. oleifera* leaves possessed poor repellent activity, and this corroborates with the result of [70].

According to [27], *M. oleifera* leaves offered 58% protection from its smoke when incorporated into a coil while 70.37% protection was offered by *O. gratissimum* coil according to [58] at moderate concentration. Therefore, the best repellent plant and repellent form from the sample leaves for repelling mosquitoes is *O. gratissimum* leaf in a coil.

3 Conclusions

The initial findings of the laboratory assessment from the previous works show the repellent potential of *M. spicata*, *O. gratissimum*, and *M. oleifera* leaves against mosquitoes. With the proper formulation of other repellent forms using their oils, they can replace non-degradable synthetic mosquito repellents since they are eco-friendly. In general, the mosquitocidal activity and percentage protection of plant extract increase with the increasing concentration of the extracts in different formulations.

The Soxhlet extraction technique is a conventional and most preferable method for obtaining plant extracts easily. However, the result from the efficacy tests revealed that natural repellents derived from plant extracts tend to provide protection for a shorter time. The active component of the *M. spicata* extract responsible for its repellent activity is carvone. While that of *O. gratissimum* and *M. oleifera* are Eugenol and 9-Octadecenoic acid, respectively. *O. gratissimum* essential oil is the best repellent plant, and its incorporation into a mosquito coil will offer the best protection against mosquitoes in comparison with the other plants and repellent forms.

Finally, the study establishes and reaffirms the potential of applying indigenous Nigerian plants' oil extracts with insecticidal properties for Mosquito control.

Abbreviations

GC-MS: Gas chromatography-mass spectrometry; FTIR: Fourier-transform infrared spectroscopy; DEET: *N,N*-diethyl-meta-toluamide.

Authors' contributions

MOE conceived the experiment and did the write-up, ORO proof-read the manuscript and DFA collated data. All authors read and approved the final manuscript.

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Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

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Competing interests

The authors declare no conflict of interest.

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